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(54) **Aircraft monitoring by data acquisition and processing**

(57) A system is disclosed for providing inertial, structural and aerodynamic data from the deflection of a flight vehicle structure due to forces acting thereon. It comprises sensors 12 distributed around the structure which provide signals proportional to the direction and magnitude of the deflections of the structure. These signals are fed to data processing arrangements 16 for detecting and isolating signals from selected ones of the sensors and converting the selected signals into inertial, structural and aerodynamic data. In a preferred embodiment of a sensor 12, light from an L.E.D. is collimated by a lens and reflected back through the lens onto a split photovoltaic cell. It can measure bending of the structure of the order of 10^{-9} radians over a range from 0 to 10,000 Hz.

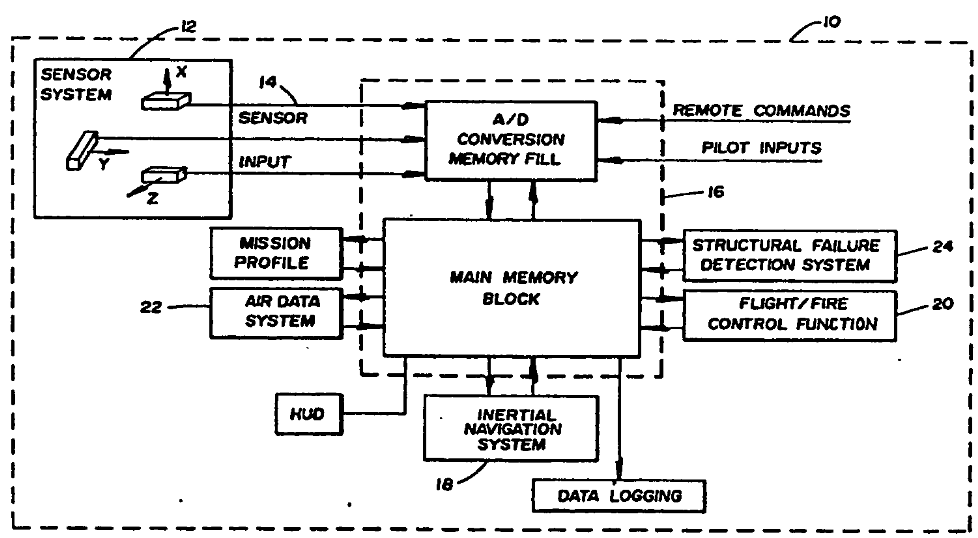

FIG. 1

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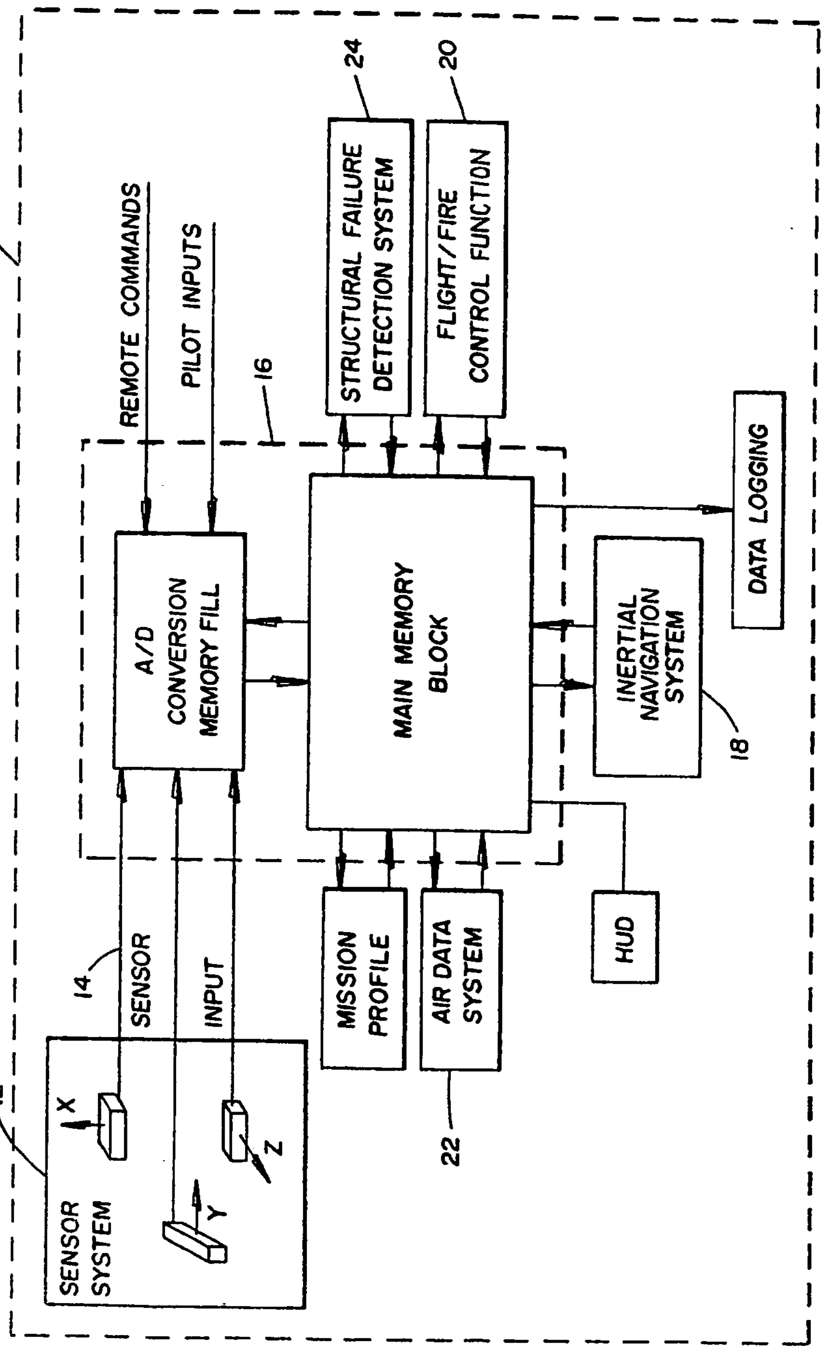
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REMOTE COMMANDS
PILOT INPUTS
16
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STRUCTURAL FAILURE DETECTION SYSTEM
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FLIGHT/FIRE CONTROL FUNCTION
A/D CONVERSION MEMORY FILL
MAIN MEMORY BLOCK
DATA LOGGING
INERTIAL NAVIGATION SYSTEM
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12
SENSOR SYSTEM
X
Y
Z
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SENSOR
INPUT
MISSION PROFILE
AIR DATA SYSTEM
22
HUD

FIG. 1

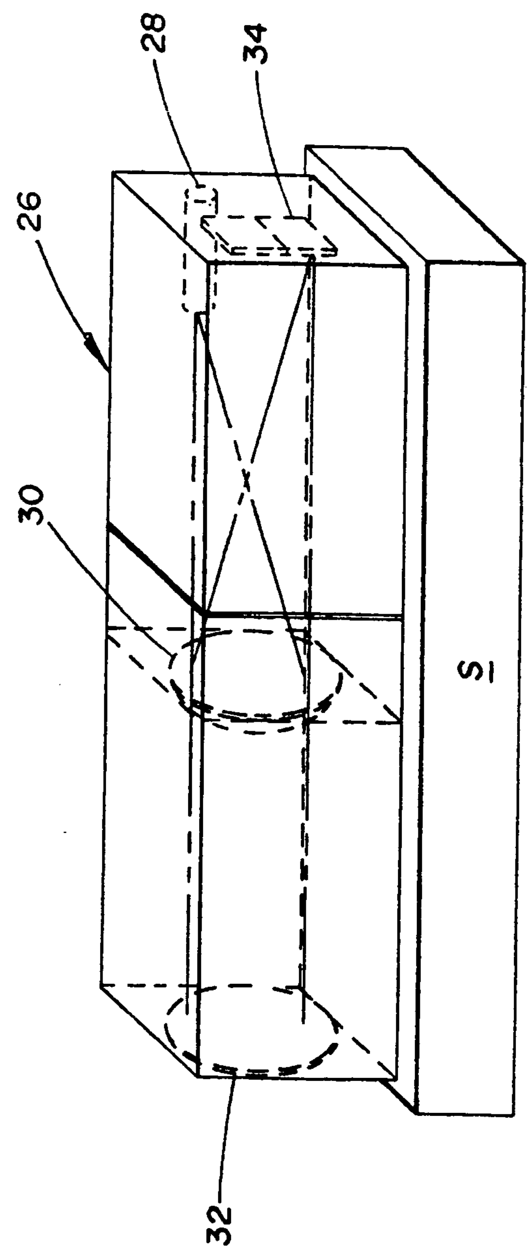

FIG. 2

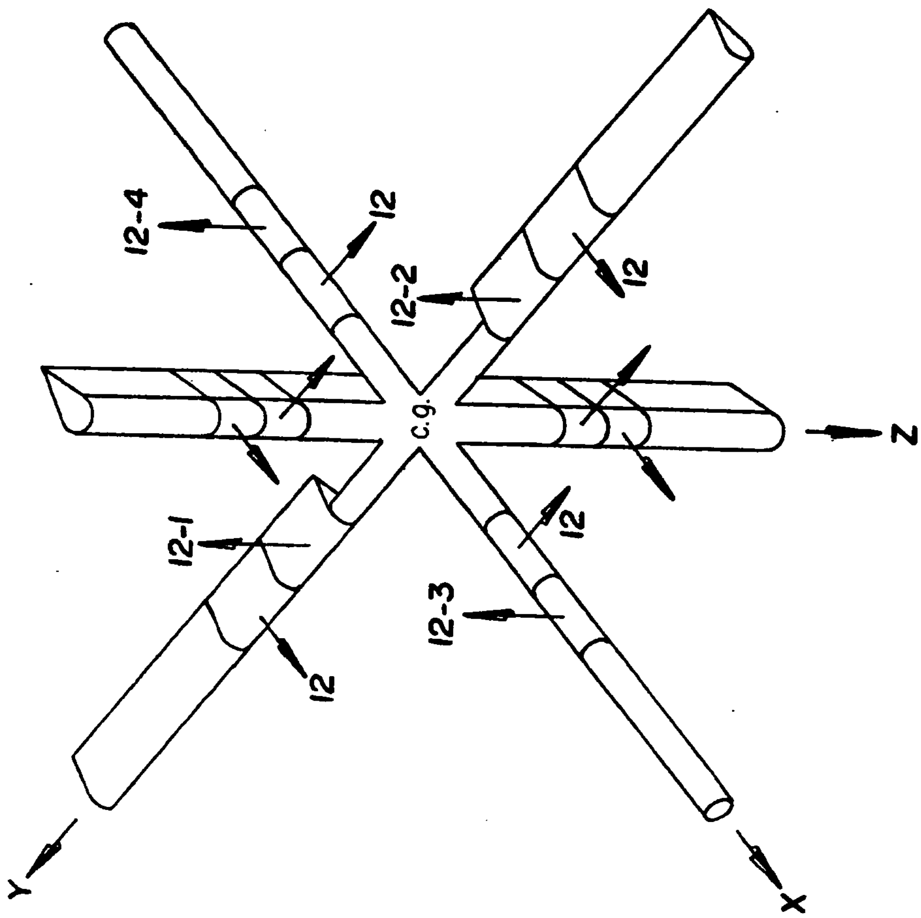

FIG. 3

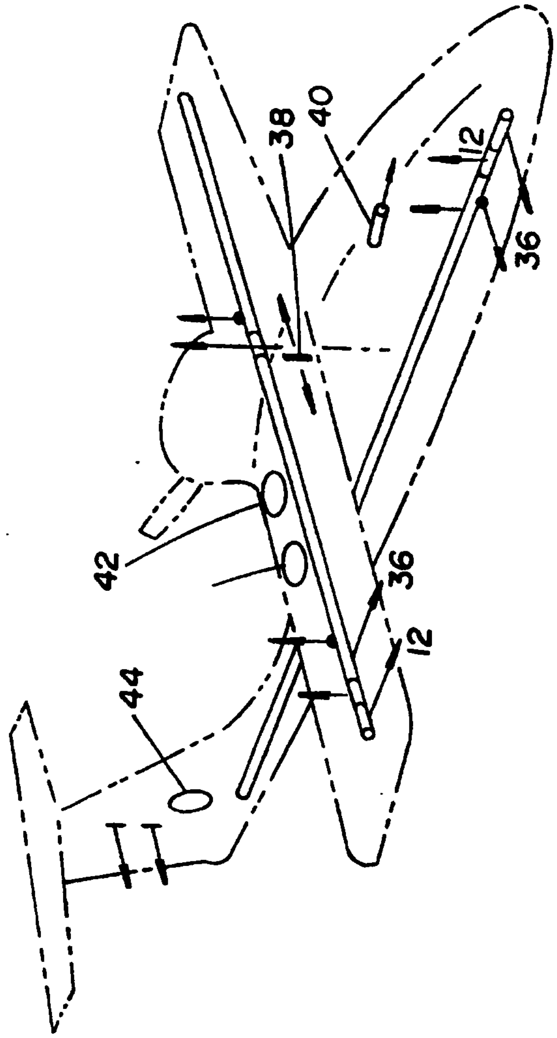

FIG. 4

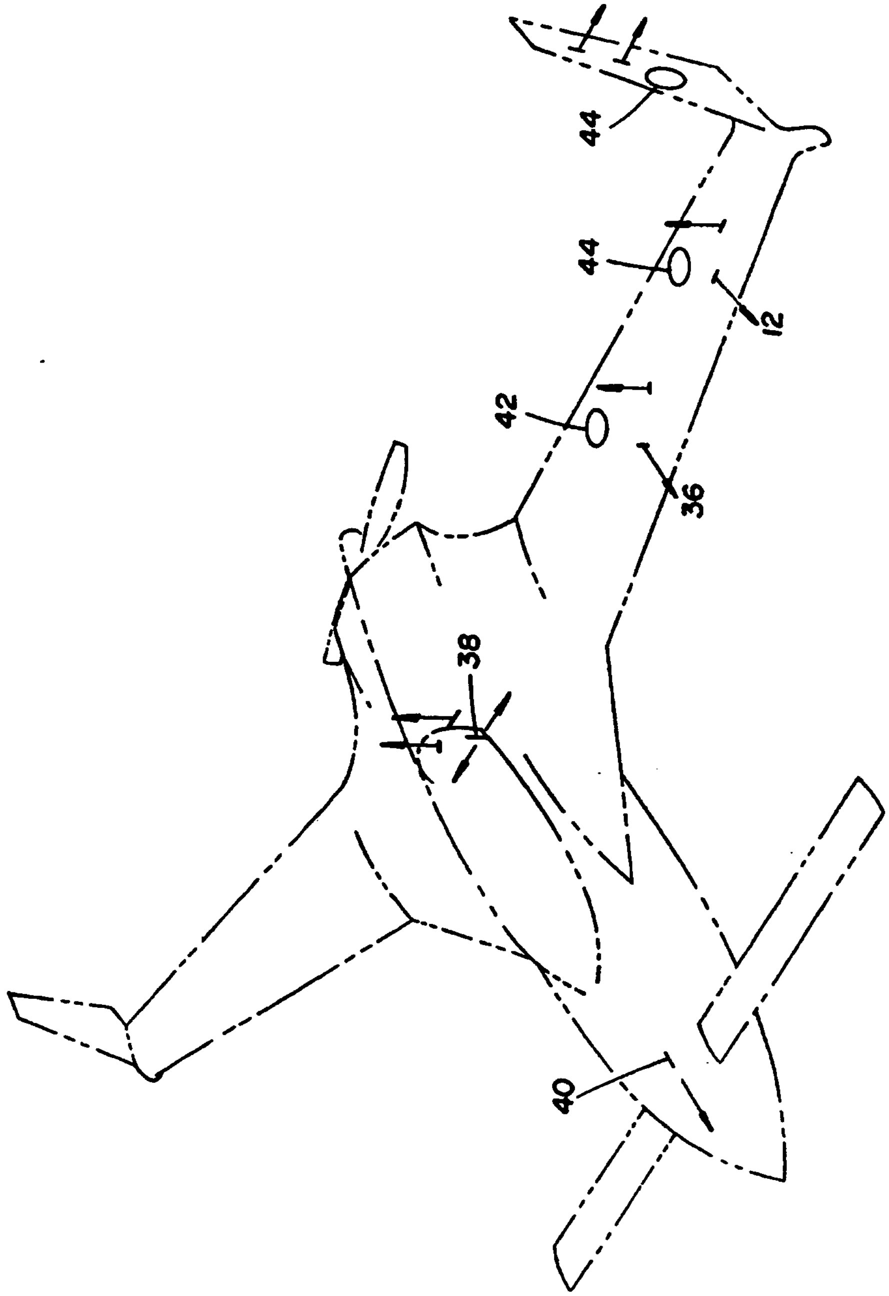

FIG. 5

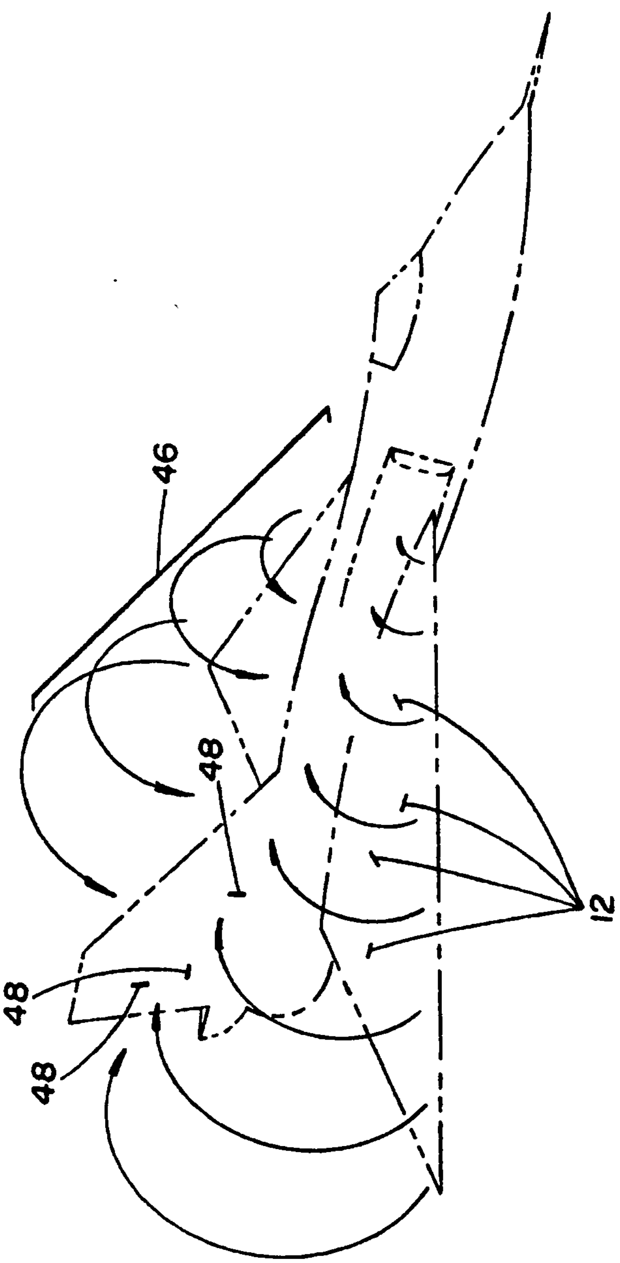

FIG. 6

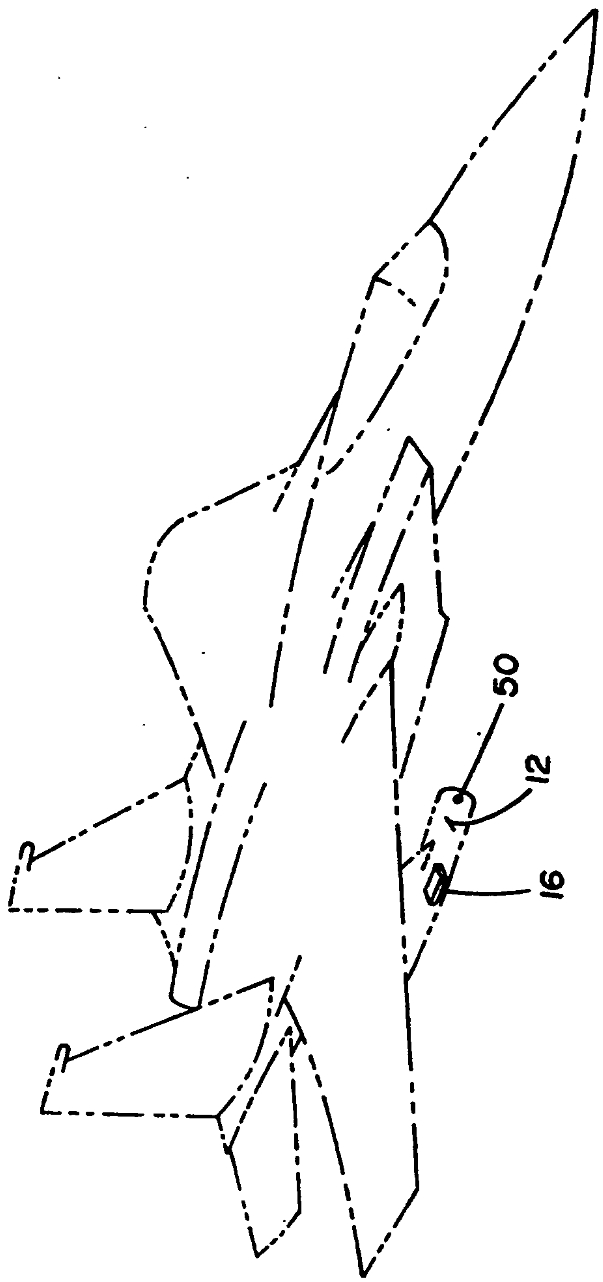

FIG. 7

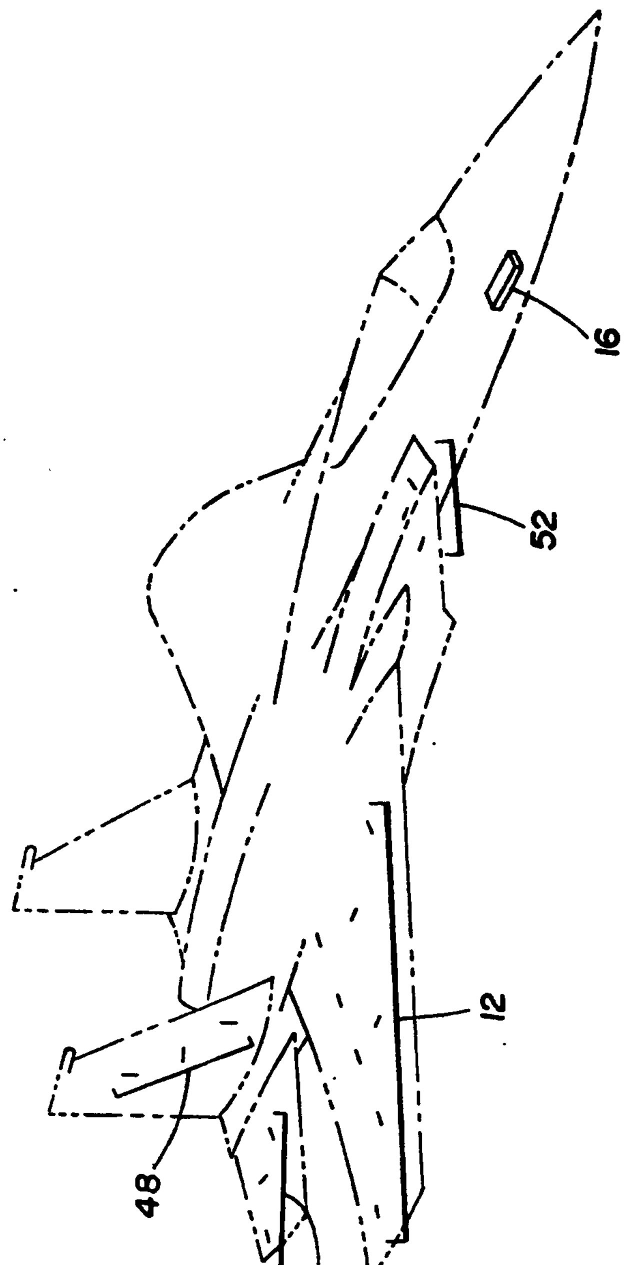

FIG. 8

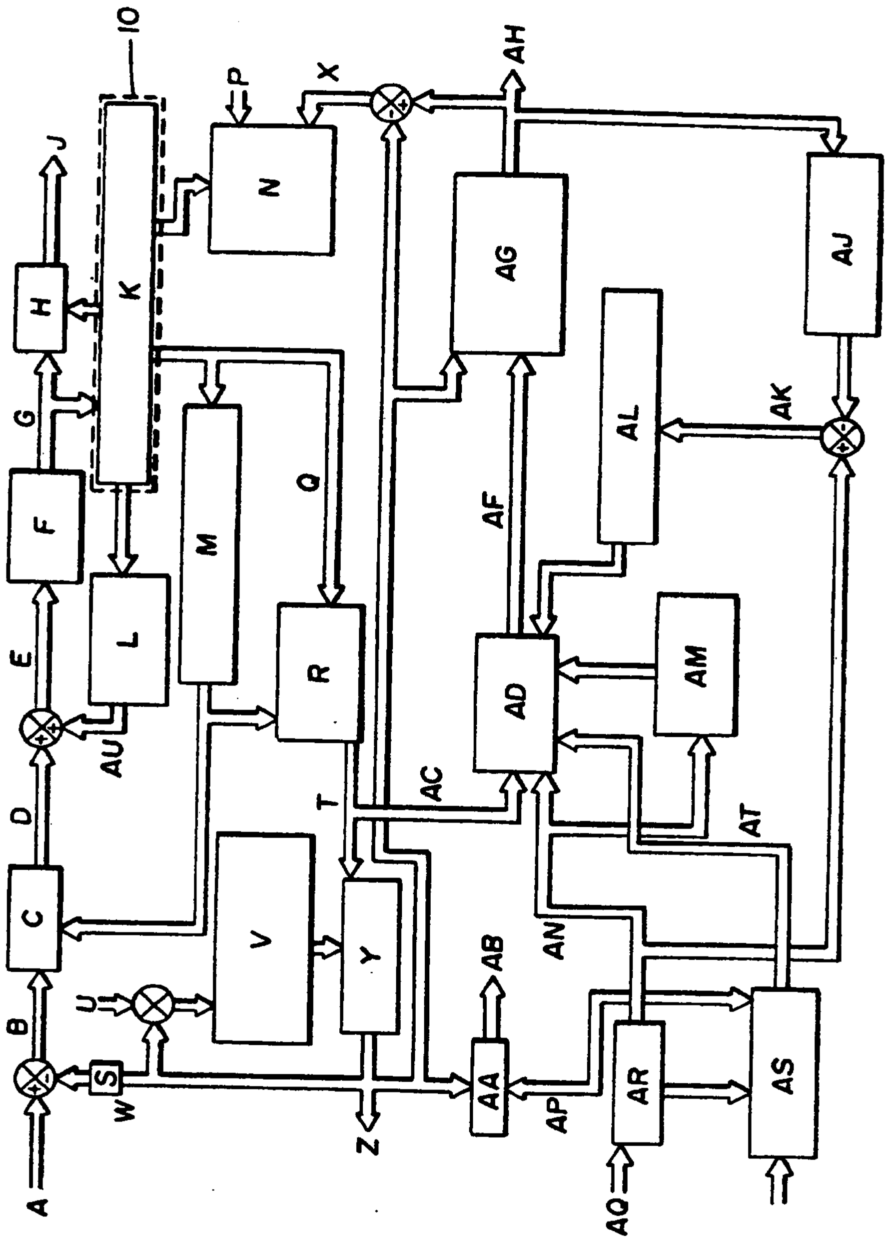
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FIG. 9

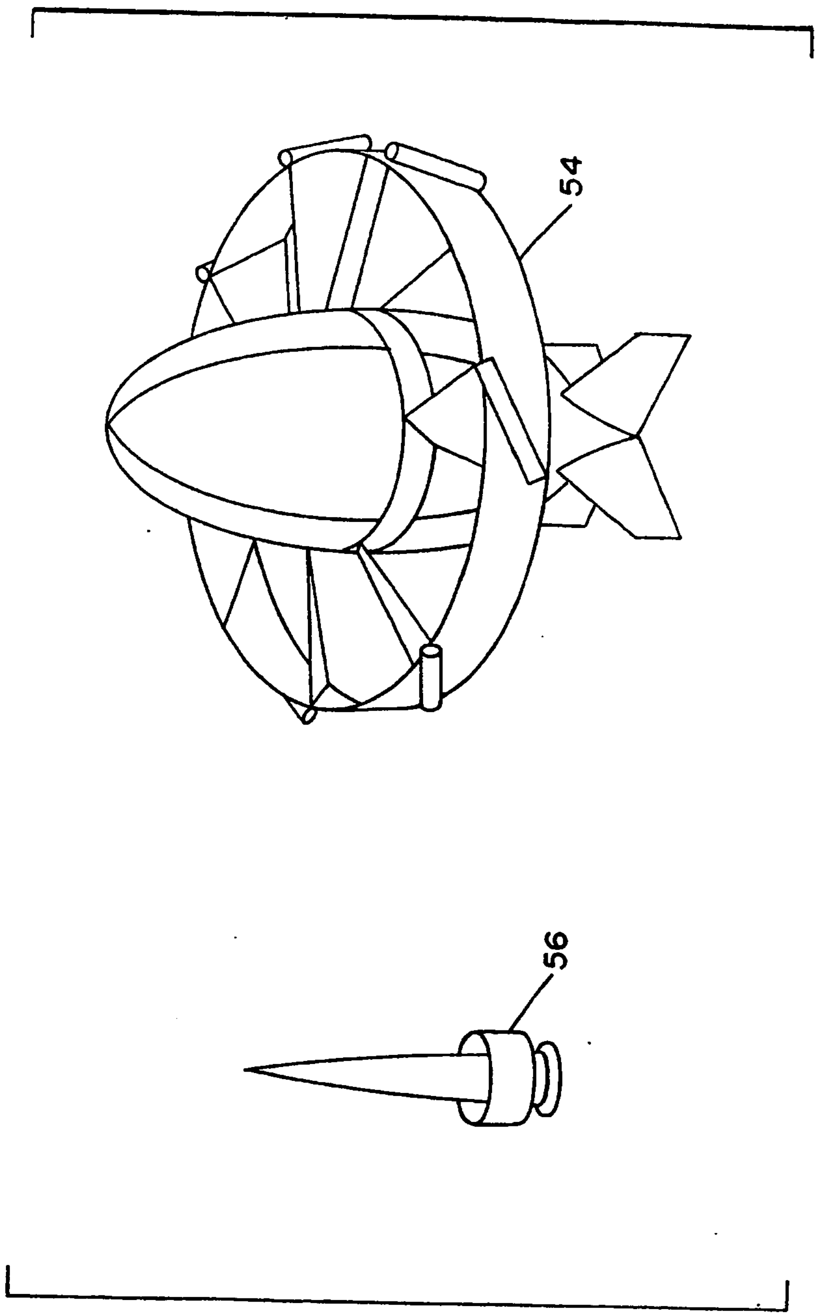

FIG. 10

SPECIFICATION

Improvements in and relating to data acquisition and processing systems

The invention relates generally to air vehicle avionics systems and more specifically to such systems designed to measure inertial, structural, and aerodynamic forces acting on air vehicles.

Inertial navigation, flight control, fire control,and structural failure detection systems may require various known types of inertial, structural, and aerodynamic data for their operation as follows:—

a. *Inertial Navigation.* It is known to obtain the inertial acceleration of the aircraft in all three inertial axes by mounting accelerometers on gyro-stabilized inertial platforms, which are carefully positioned near the aircraft's centre of gravity (cg) and isolated from structural and aerodynamic disturbances.

b. *Flight Control.* The principal sensors known for association with flight control systems are inertial sensors including rate gyros and accelerometers together with aerodynamic measurement systems. It is known in flight control systems to include quadredundant rate gyro packages to provide four measurements of pitch, roll, and yaw rate. Such sensor assemblies are also located as near the aircraft cg as possible, and on a structural mode. A typical state of the art accelerometer configuration includes eight identical, force-balanced accelerometers, four to sense normal, and four to sense lateral-direction, accelerations. More advanced systems include thrust axis accelerometers to measure propulsive aerodynamic forces to implement automatic throttles. All of these inertial measurement devices are precisely located so as to yield minimum body-bending effects and maximum aerodynamic stability. They are generally located as near to the aircraft centre of percussion as practical. Such flight control systems may also include a computer which generally receives input signals from basic pilot commands, trim commands, aerodynamic data, and inertial sensors. Modern flight control sensor performance, nominal rate gyros and accelerometers are capable of the following performance:

PARAMETER	RATE GYRO	ACCELEROMETER
Range	300 deg /sec	± 12 g
Gradient	20 MV/deg /sec	0.417 V/g
Natural Frequency	>48 Hz	275 Hz
Damping Ratio	1.4	>1.0
Threshold	0.01 deg /sec	0.00001 g

c. *Fire Control and Weapon Delivery.* Strapdown or gimballed target tracker and weapon sensors can be used to determine target and weapon state. In lead computing optical sights, a rate integrating gyro determines the target lead angle. The quality of these gyros is significantly better than the gyros required for flight control systems, although the redundancy requirement is less severe. Fighter aircraft of the future, which employ director-type fire control systems to accurately measure the target Line-of-Sight will require both high precision angular location and angular rates of the tracking sensor. significant sensitivity introduced into the fire control system by uncertain measurements of inertial, structural, and aerodynamic data may produce errors.

d. *Air Data.* It is known to use air data sensors including angle-of-attack and side-slip vanes and cones, or multi-port pressure probes or a combination of these. Pitot-static systems are used to measure static and impact pressure from which dynamic loading, airspeed, Mach number and other key air data are computed in a central air data computer. This data is subsequently used to feed instruments, schedule flaps, or gains in the flight control system, and limit pilot control for safety-of-flight. Existing air data sensors are capable of the following accuracy levels:

PARAMETER	ACCURACY
Velocity (true airspeed)	± 5 knots
AOA	1 degree
BETA	1 degree

It should be noted that air data sensors are generally calibrated and compensated for temperature effects, but only measure aerodynamic data at a point unaffected by the flow around the aircraft. They are generally incapable of measuring small scale flow phenomena such as separation, turbulence, vortex patterns, and flutter which are important to an aircraft's safety and control.

e. *Structural Failure Detection.* The type of structural failure detection performable in flight is generally limited, but is generally of the stress magnitude or fatigue test variety. As many as 100 strain gauges may be installed in critical sturctural areas. These gauges generally have a low frequency response and are generally capable only of detecting structural fatigue or catastrophic failure after it occurs.

The foregoing examples of prior art indicate that various inertial, structural, and aerodynamic data are obtained by a wide variety of different sensors, where each sensor is generally dedicated to obtaining a single piece of information. It is also typical of such systems that the sensors be carefully installed to assure that no unwanted

inertial, aerodynamic, or structural data is inadvertently sensed.

An object of the invention is to provide improved systems and methods for measuring data relating to air vehicles.

BRIEF SUMMARY OF THE INVENTION

According to the invention, there is provided a system for providing inertial, structural, and aerodynamic data from the deflection of a flight vehicle structure and induced by the forces acting on the structure, comprising first means including sensors mounted on said structure and operative to provide signals proportional to the direction and magnitude of the deflections of the structure associated therewith as a result of applied force, and second means for detecting and isolating signals from selected sensors and converting said selected signals into inertial, structural, and aerodynamic data.

According to the invention, there is also provided a method of providing inertial, structural, and aerodynamic data for a flight vehicle derived from measurement of the structure of the vehicle which comprises the steps of:—

(a) measuring the forces applied to the structure by detecting the magnitude of deflections of the structure caused by the applied forces;
(b) providing signals indicating the direction and magnitude of the structural deflexion; and
(c) selecting and compiling predetermined signals based on the location of the applied forces relative to the structure to provide data indicative of the effect of the forces on the aircraft.

In embodiments of the invention to be described, distributed multi-input and multi-output sensing sensors are used. Such sensors essentially make only one type of measurement — the deflection or bending of the structural member in the vicinity of the sensor. This therefore contrasts with the use of numerous single-input, single-output sensors which operate on widely different principles to detect inertial, structural, and aerodynamic forces and to isolate such forces from the other forces not to be measured.

Systems and methods according to the invention for measuring and processing data affecting aircraft will now be described, by way of example, with reference to the accompanying drawings in which:—

Figure 1 is a block diagram of one of the systems, capable of providing inertial, structural, and aerodynamic data;

Figure 2 is a schematic diagram of a flexural rigidity sensor for use in the system;

Figure 3 is an idealised representation of the structure of an aircraft for use in explaining the operation of the system;

Figure 4 shows the system as applied to a simple remotely-piloted vehicle, drone, or missile;

Figure 5 shows the system as applied to a light aircraft composite structure;

Figure 6 shows the system as applied to a high angle of attack flight control and to structural failure detection;

Figure 7 shows the system as applied to the determination of the orientation of a tracker for a gun director system;

Figure 8 shows the system as applied to a fighter aircraft for performing inertial navigation, flight/fire control, engine and light control, and structural failure detection;

Figure 9 is a block diagram of a form of the system for flight and fire control system; and

Figure 10 shows hypersonic and supersonic structures with integrated aerodynamic, propulsive, structural, and inertial functions made possible by use of the systems.

Figure 1 shows by way of example one form of the system 10. System 10 provides data for flight vehicles which, for example, enables the vehicle to navigate inertially and control its flight and weapon path, and also indicates an impending structural failure of the vehicle from measurements of the deflection for bending of the structural members.

System 10 comprises a structural sensor 12 which is physically attached to a structural member of the structure of the aircraft or air vehicle. The sensor 12 measures the deflection or bending of the structural member resulting from forces acting on the member. The output signals 14 from the sensor 12 are directed to a data acquisition system 16. The acquisition system 16 converts signals 14 from analog to digital form, loads the digital signals into a memory, and converts the sensor data into inertial, structural, and aerodynamic data for use by an inertial navigator system 18, a flight/fire control system 20, an air data system 22, and a structural failure detection system 24.

In order to provide the required signals 14, sensor 12 must be capable of detecting or measuring deflections of the order of intermolecular spacing which is of the order of 10^{-9} radians over a bandwidth from 0 to 10,000 Hz.

The flexural regidity sensor (FRS) 26 illustrated for example in Figure 2 can be used as the sensor 12 and makes these accurate measurements possible. The sensor 26 includes a light emitting diode 28 fixed to the structure *S* which directs its light through a lens 30 which collimates it for reflection by a mirror 32. The light beam is reflected through the lens 30 onto a split photo-voltaic cell 34 which measures changes in photons impinging thereon due to bending of the structure. The sensor 26 makes this measurement of the order of intermolecular size by detecting and measuring the shift in the reflected beam on the split photo-voltaic cell resulting from minute forces imposed on the structure. For example, the effect of removing a dollar bill from an aluminium bar measuring 1.27 cm by 5.08 cm by 30.48 cm can be detected by the sensor. Sensor 26 is not

only capable of measuring such small deflections in the structure, but it is also relatively inexpensive to produce. Hence, it becomes an ideal sensor for use in system 10 because many sensors are required per aircraft.

The exceptional accuracy obtained by sensor 26 is believed to result from its extremely rapid response time, of the order of 1/3 nano second (the time taken for a photon to traverse the optical path between the light emitting diode 28 and split photo votaic cell 34). This allows the sensor 26 to utilise the order of 100,000,000 independent measurements of a typical structure vibration of approximately 30 Hz. Averaging these measurements would normally induce 10,000 times better accuracy than the accuracy of the basic device. The accuracy of sensor 26 at very high frequencies is clearly one micron (the wavelength of the light emitted from the diode) measured at a distance of approximately 0.1 metre. This indicates that measurements of the order of 10^{-9} radians can be made at typical structural frequencies. Accuracies of this order have indeed been experimentally observed.

It has been discovered that such accuracies allow sensor 12 to measure essentially all structural deflections induced by either inertial, structural, or aerodynamic forces on a flight vehicle. Therefore, sensor 12 when utilised with appropriate statistical inference techniques has the possibility of generating heretofore unobtained inertial, structural, and aerodynamic data from a destributed sensor system.

The separation of the inertial, structural, and aerodynamic forces is accomplished by observing the difference in their effects on the structure as a whole. By way of example, Figure 3 shows an idealised version of a flight vehicle structure to illustrate how the system separates inertial, structural, and aerodynamic forces. In Figure 3, in each of the three axes there are four sensor arrangements 12 attached on either side of the centre of gravity, cg, measuring axis deflection in the two other perpendicular directions.

Inertial acceleration (including gravity) along any of the three axes, x, y, z, will tend to bend the structure symmetrically and normal to this axis. Angular accelerations about any of the three axes, x, y, z, will tend to bend the structure asymmetrically and perpendicular to the axis. Therefore, a downward linear acceleration results in an upward deflection of both wings, nose, and tail of the aircraft, whereas an angular acceleration about the x-axis results in a downward deflection of the right wing and upward deflection of the left wing and no deflection of the nose and tail.

Then, an asymmetrical deflection of the left and right wing without a deflection of the tail is a measure of angular acceleration about the x-axis, whereas an upward deflection of the nose, tail, left and right wing is a measure of downward acceleration. Therefore, when sensors 12—1, 12—2, 12—3, and 12—4 measure an upward deflection alone, it is interpreted as a linear acceleration along the positive z-axis (down). When sensors 12—1 and 12—5 give a positive output and sensors 12—2 and 12—6 give a negative output, it is interpreted as an angular acceleration about the x-axis proportional to the mean output of the sensors.

Aerodynamic data is obtained by observing that its effect dominantly induces bending of the wings and tail while leaving the aircraft nose generally unaffected. Engine mount deflections in the direction of thrust can be utilised to obtain engine aerodynamic forces.

Higher frequency and smaller scale aerodynamic and structural forces associated with separation, turbulence, shedding vortex sheets, and engines are obtained by measuring small scale deflections of the structure in the affected area. Coupling between these lower frequency inertial and aerodynamic forces and higher frequency structure and aerodynamic phenomena can be readily accounted for as the coupling the small.

Aerodynamic forces (drag, lift, and side force) produce symmetric bending proportional to the square of the velocity through the air (air speed) and density or equivalent dynamic pressure, depending upon the orientation of the structure relative to the air mass velocity. Therefore, a positive output from sensors 12—1 and 12—2 with no other appreciable output is interpreted as an aerodynamic load due to a velocity component in the x, z plane (angle of attack). An output from sensors 12—5 and 12—6 with no other appreciable sensor output is interpreted as aerodynamic deflections due to an air mass velocity in the x, y plane (sideslip). Four sensors with normal axis of sensitivity located as illustrated are therefore sufficient to resolve any arbitrary combination of inertial and aerodynamic forces. In fact, the minimum number of sensors required is nine, the number of states being identified. The redundant sensors aid significantly in structural integrity identification which will be disclosed next.

There are essentially two independent methods of detecting failure of a structure, one involving measuring the frequency response of a structure and its variability with time other than that induced by inertial and aerodynamic loading. The second method involves recording the stress waves in the structure induced by cracking or other structural failure. It will now be explained how the systems disclosed are used to perform both the functions.

Most aircraft structures can be considered to be nearly elastic systems. Even structures formed with composite materials have vibration characteristics which are well-defined and repeatable. It is known, both analytically and experimentally, that the natural modes of vibration of a structure are distinct, well-defined and a function of the physical dimensions of the structure, the inertial properties of the material, and the mean load. Any changes in these factors will change the natural frequencies and the

associated vibrational modes of the structure.

With information sensed from the wide band sensors 12, the changes in the frequencies of the natural modes of the structure due to changing physical dimensions, loading, and internal material properties will be determined by the data acquisition system or microprocessor 16. Each structure will have a distinct set of natural frequencies associated with a given loading and, as such, will have a well-defined impulse response when the structure is new, unfatigued, and with no cracks existing. When changes occur, such as cracking or fatiguing, the impulse response will change due to changing natural frequencies of the structure. By means of the microprocessor 16, the effects on the structure due to loading are removed and the remaining changes are due to changes in structural properties, excluding temperature. This continuous identification of either the impulse response, or equivalently the frequency spectrum of the structure, will allow for identification of structural changes of appreciable size.

To implement active crack detection in an air vehicle that has been optimised for strength-to-weight ratio, where many components operate near the structural limits, requires an alternative real time approach. In such aircraft, the materials used, such as aluminium, fibreglass and advanced composites, fatigue readily, reducing the useful life of the aircraft. If such an aircraft is subjected to inadvertent adverse loads or the structure material has unsuspected material defects, the onset of structural failure may occur with a catastrophic result. Early warning of such a failure may be manifested by exceedingly small cracks in the structure. These extremely small cracks can result in structural failure in a relatively short time. The state of the art procedure for crack detection in aircraft involves visual and/or electronic inspection of the aircraft on the ground. Since extremely small cracks are of great significance in these types of structures, inspection procedures are costly and relatively ineffective.

Active crack detection involves the detection of these exceedingly small cracks as they occur in flight. The formation of cracks involves a substantial release of strain energy. The release can be detected by sensors 12 and when recorded by microprocessor 16, the occurrence of the crack can be separated from the effects of inertial and aerodynamic forces simultaneously inducing the observed structural deflections.

Cracks occur in a material in an attempt to relieve the stress created by incident forces. This results in a release of strain energy. This energy is expended in essentially two forms: 1) the formation of the surface of the crack, and 2) the kinetic energy for crack propagation.

It is well-known that the crack velocity is significantly less than the velocity of sound in the material. For example, in aluminium, the crack velocity is no more than 3/10 the speed of sound in the material. Therefore, if a crack propagates only a short distance, the acoustic fault has already been transmitted through the structure and is sensed by the sensor 12. This phenomenon is similar to an explosion in the air where the shock wave propagates much faster than the explosive products.

Materials, such as glass at room temperature, undergo brittle fracture. The same is not true of metals, for instance, which are capable of deforming by slip and twinning even at very low temperatures. It has been observed that even when a metal fails by brittle cleavage, a certain amount of plastic deformation almost always occurs prior to fracture. Metals therefore do not fracture as a result of pre-existing cracks but, in many cases, by cleavage cracks nucleated as a result of the plastic-deformation process. Present theories favour the concept of dislocation interactions as inducing cleavage nuclei. Dislocations on different slip planes can combine to form new dislocations on the fracture plane, thereby opening a crack. Alternatively, slip on a given plane can be impeded by some sort of barrier leading to a pile-up of dislocations which, in turn, nucleate a crack. An obstacle to slip must be very strong so that it can stand the high stress at the head of the dislocation pile-up. Deformation twins and grain boundaries are obstacles with sufficient strength to stand the high stress.

Therefore, in materials such as metals, energy is lost due to plastic deformation in addition to crack formation. When slip takes place during the movement of a crack, energy is absorbed in nucleating and moving dislocations. If the energy required to overcome plastic deformation becomes too large, the crack may decelerate and stop. Thus, detection of these cracks after they occur is a very difficult task. At the instance of crack occurrence, however, energy release is significant as evidenced by the release of strain energy. This energy release will excite lightly driven high frequency modes and drive acoustic waves within the material. Because of the frequency response of the sensor 12, it can easily detect this energy release. Because of the sharpness of the pulse, time of arrival techniques can be used to ascertain the approximate location of the acoustic pulse.

Certain characteristics of the aircraft which change slowly over its lifetime, such as elasticity of the various structural members, may be initially calibrated by observing deflections under ground test conditions and thereafter continuously monitoring the vibrational mode frequencies and shapes. Impending structural failure can be observed by changes in these mode shapes and frequencies in a manner unanticipated due to inertial and aerodynamic loading.

Initial calibration of the aerodynamic coefficients may be accomplished by flying aircraft on specified paths, such as high speed taxi runs and take-offs that terminate in an immediate landing on the same runway, possibly in opposite directions to eliminate the effect of wind, after performing such prescribed manoeuvres as stalls, turns, and high speed passes. Changes in

aerodynamic coefficients due to environmental conditions, such as rain or ice, are then observable as changes in deflections without associated changes in elasticity as observable through structural frequency of the natural mode. Rapidly changing variables, such as aircraft mass, can be initially calibrated by observing deflections of the landing gear and suspension points on the ground, and thereafter estimated by counting engine cycles and observing changes in mode shapes and frequencies associated with fuel depletion.

With these techniques, structural deflections which may be produced by aerodynamic loading (lift, side force and drag), inertial loading (g loading), thermal loading, engine vibration loading, transient aerodynamic loading, and the operation of aircraft subsystems (i.e. drag brakes, landing gear, flaps, and engine controls) can be effectively separated. A further feature of the systems being described is a calibration technique necessary to obtain these results. It is extremely difficult to calibrate the structure so that there is reasonable assurance that the proper force components have been identified. So a continuous calibration technique must be undertaken.

It is further possible to miss certain structural modes by inappropriate sensor location. Another feature of the systems being described is a method of choosing such sensor locations initially and further improving these locations to obtain resolution of the applied inertial structure of aerodynamic forces. Still another feature is the ability to redesign flight vehicles to obtain better integration of various aerodynamic, propulsive, structural and inertial subsystems.

Sensor outputs are fed into data acquisition system 16 where they are processed and converted into data usable by the operating systems of the air vehicle such as inertial navigation system 18, flight/fire control system 20, air data system 22, and structural failure detection system 24.

The raw data in the form of signals 14 is presented by sensor 12 to the data acquisition system or microprocessor 16. System 16 provides interpretation, qualification, and correction of the raw data. The system 16 performs these functions in accordance with the following criteria:—

1) System 16 must be able to acquire and store the data from each sensor 12 at a rate commensurate with the input signal frequency content. To meet the minimum rates specified by accepted theory, this rate will have to be as high as 30,000 samples per second.

2) The interval between sample points must be accurately controlled and dependent only on a real time clock.

3) The absolute time of each sample must be known.

4) The system must be able to react to inputs outside the normal range of values in some manner which guards against false interpretation.

5) Adaptive processing must be implemented in the event of anomalies in the input data stream. This process must be implemented such that it is triggered by the event regardless of the clock time

6) The system must permit asynchronous inputs from several sources based upon a strict priority structure.

7) Oznamic rescaling and/or recomputation must be available. All of these requirements are met by available configurations of the Model RTD-99 data acquisition computer manufactured and sold by Research, Analysis and Development, Inc. of Colorado Springs, Colorado, U.S.A. Specific configurations will be determined by specific system data rates and sensor array dimensions.

Complex computation and/or high data rates required by system 16 require subsystems whose construction must permit communication of sensor data to the computation subsystem without interference with the basic real time imperatives of sampled data stream. The RTD-99 computer mentioned above provides this communication and permits run time rescaling based upon multiple levels of absolute priority conditions.

In addition to the above constraints, the system 16 allows flexible communication of processed sensor data to systems which will make specific interpretation of the data to produce operator-usable information (i.e., air data systems 22, failure system 24, and flight/fire control system 20, all of whose design will be apparent to those skilled in the art).

Applicable information is provided in each of these systems as required. Air data computation system 22 is provided with all sensor data necessary to determine aerodynamic forces such as airspeed. The structural failure system 24 is supplied with forces and times to define structural time histories. Inertial navigation 24 and flight/fire control 20 systems require forces and rates resolved to specific axes and are provided only to those reduced data inputs.

Figure 4 shows by way of example a relatively simple flight vehicle such as a drone, remotely piloted vehicle or missile. The magnitudes of the first asymmetric and symmetric modes are used to infer inertial and aerodynamic forces in a manner not substantially different from the idealized structure shown in Figure 3. Known angular motion rate sensors 36, such as of magnetic or capacitive type, can be utilised for high frequency response. Further, bending of engine mounts is utilised to infer angular velocity in the two axes perpendicular to the engine's angular momentum. Deflections in the direction of the angular momentum are used to infer aerodynamic thrust of the engine. Angular velocity about the engine's angular moment axis can be inferred with a known Hector Schuler pendulum 40. Further, known electrostatic transducers 42 and electromagnetic transducers 44 can be utilised to produce measurements to aid in reinitializing the dominant rate in acceleration measurements provided by system 10. The system disclosed represents the only known method of producing quality inertial and aerodynamic measurements economically consistent with the low cost of these vehicles.

Figure 5, by way of example, shows the system applied to a General Aviation light aircraft. Here, the additional function of structural integrity assessment is added to the previously described system. The system not only produces inertial and aerodynamic data for inertial navigation and flight control precision consistent with the cost of such aircraft, but also the structural integrity assessment techinques allow the detecting of impending failure. This provides the only economically feasible method to certify aerodynamically and structurally efficient composite structures.

Figure 6 by way of example, shows the system applied for performing high angle-of-attack flight control functions. Here the problem is not only to establish inertial body rates and accelerations for use in the flight control system, but to measure the reimpingement of the shedding vortex sheet 46 from the wing onto the tail 48. Without the use of distributed sensors 12 capable of such small aerodynamic measurements, detection of an impending out-of-control manoeuvre is impossible.

Figure 7 by way of example shows the system as applied to an orientation and rate measurement device for a tracker in a modern gun director fire control system. Sensor 12 functions to measure the tracker pod orientation and rate relative to the central fire control-computer reference axis. Structural bending of the order of ten milliradians essentially defeats the gun director system's ability to infer target position, velocity and acceleration to the accuracy require for fire control. The present system is therefore needed to implement this fire control system.

Figure 8 by way of example shows the system used in a high performance F—15 fighter. System 10 is performing the previously identified inertial navigation 18, flight and fire control functions 20 together with engine inlet control measurement 52 and structural failure detection 24 measurement. The small scale deflections in the area of the inlet are utilized to determine the location of the shock wave and to detect minute failures of the individual strands of the high performance composite structure. System 10 teaches the only known method of obtaining measurements to perform the functions consistent with the performance requirements of this modern fighter.

Figure 9 by way of example shows a block diagram of a flight/fire control system in which system 10 is being utilised to infer, not only inertial and aerodynamic measurement, but to measure aerodynamic control and infer the associated vehicle aerodynamic coefficients. It is also utilised to infer gun dispersion. The existence of system 10 allows for the implementation of the versatile and functional fire/flight controls illustrated.

Figure 10 by way of example shows two structures, one supersonic 54, another hypersonic 56, in which aerodynamic, propulsive, flight control and navigation functions have been integrated in a manner that is only possible with the use of the systems disclosed herein. Such flight vehicles are capable of dramatic improvements in performance, safety and cost over competitive, conventional vehicles.

Therefore, the systems described are capable of inferring inertial, aerodynamic and structural forces acting on a flight vehicle for use in inertial navigators, flight control, fire control, air data engine performance, and structural failure subsystems in a manner heretofore unknown. These systems provide the measurements for economical inertial navigators, effective gun director fire control systems, feasible high angle of attack flight control systems, and effective structural failure detection systems. The systems allow design of highly integrated flight vehicles that provide dramatic improvement in aerodynamic, propulsive, structural and navigation efficiency.

CLAIMS

1. A system for providing inertial, structural, and aerodynamic data from the deflection of a flight vehicle structure and induced by the forces acting on the structure, comprising first means including sensors mounted on said structure and operative to provide signals proportional to the direction and magnitude of the deflections of the structure associated therewith as a result of applied force, and second means for detecting and isolating signals from selected sensors and converting said selected signals into inertial, structural, and aerodynamic data.

2. A system according to claim 1, wherein said sensors measure the bending of the structure of the order of 10^{-8} radians over a range from 0 to 10,000 Hz.

3. A system according to claim 2, wherein said sensor comprises a light source, a reflective surface axially displaced from said source, lens means for collimating light onto said reflective surface and a split photovoltaic cell adjacent to said source and axially spaced from said reflective surface, and whereby said sensor generates a signal proportional to a shift in the area of impingement of the reflected light on said cell which is dependent on structural deflection.

4. A system according to claim 2 or 3, including means for locating said sensors relative to the axis of the flight vehicle whereby selection of the signals produced by said sensors provides inertial, aerodynamic and structural data.

5. A system according to any preceding claim, including means for locating said sensors relative to the structure to provide data from the signals indicative of the integrity of the structure.

6. A method of providing inertial, structural, and aerodynamic data for a flight vehicle derived from measurement of the structure of the vehicle which comprises the steps of :—

(a) measuring the forces applied to the structure by detecting the magnitude of deflections of the structure caused by the applied forces;

(b) providing signals indicating the direction and magnitude of the structural deflection; and

(c) selecting and compiling predetermined signals based on the location of the applied forces relative to the structure to provide data indicative of the effect of the forces on the aircraft.

7. A method according to claim 6, wherein the measuring step includes the step of detecting deflections in the structure of the order of 10^{-9} radians over structural vibration frequencies of interest.

8. A method according to claim 6 or 7, wherein the selecting and coupling step includes the step of selecting signals identifying structural deflections about the principal axes of the vehicle to provide data indicative of the inertial, aerodynamic and structural movements of the vehicle about the axes.

9. A method according to any one of claims 6 to 8, including the step of evaluating the data obtained from measuring structural deflection at a particular location on the structure and relocating the area of the measured structural deflection to obtain more pertinent applied forces acting on the structure.

10. A system for providing inertial, structural, and aerodynamic data from the deflection of a flight vehicle structure, substantially as described with reference to Figure 1 of the accompanying drawings.

11. A system for providing inertial, structural, and aerodynamic data from the deflection of a flight vehicle structure, substantially as described with reference to Figures 1 and 2 of the accompanying drawings.

12. A system for providing inertial, structural, and aerodynamic data from the deflection of a flight vehicle structure, substantially as described with reference to all the Figures of the accompanying drawings.

13. A method for providing inertial, structural and aerodynamic data from the deflection of a flight vehicle structure, substantially as described with reference to Figure 1 of the accompanying drawings.

14. A method for providing inertial, structural, and aerodynamic data from the deflection of a flight vehicle structure, substantially as described with reference to Figures 1 and 2 of the accompanying drawings.

15. A method for providing inertial, structural, and aerodynamic data from the deflection of a flight vehicle structure, substantially as described with reference to all the Figures of the accompanying drawings.

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